CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-237

SPRINGVILLE, CAMARILLO AND RELATED FAULTS

in the Camarillo and Santa Paula Quadrangles

Ventura County, California

by
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INTRODUCTION

The Springville and Camarillo faults are at the western end of the Simi-Santa Rosa fault zone, a prominent reverse fault system that extends for over 25 miles (40 km) across Ventura County, from the northeastern end of Simi Valley westward to the Camarillo Hills, east of the Oxnard Plain (Figure 1). A largely unmapped element of this fault system, the "Santa Rosa Valley fault", is proposed to exist within the Santa Rosa Valley.

The purpose of this study is to evaluate the westernmost portion of the Simi-Santa Rosa fault zone and determine whether individual fault traces are sufficiently active and well defined to be included in a new Alquist-Priolo Earthquake Fault Zone (Hart, 1994). Although the Springville and Camarillo faults were previously evaluated (Smith, 1977b&c, respectively), there was insufficient evidence to include the faults within an Earthquake Fault Zone. However, recent studies on the Springville fault have found evidence of Holocene faulting. A postulated northwest-trending tear fault ("Wright Road fault") at the western end of the fault system is also evaluated. The study area includes the northern portion of the Camarillo 7.5' quadrangle and the southern portion of the Santa Paula 7.5' quadrangle (Figure 1). Other faults that lie within the study area will be briefly addressed. The eastern continuation of this structural zone will be addressed in a future evaluation.

CAMARILLO FAULT

Summary of Available Data (Figure 2)

The Camarillo fault was first identified, although not named, by Bailey (1951). One of the earliest published maps of this fault was by the State Water Resources Board (1956), showing a largely concealed fault extending from Camarillo (where it defines the southern margin of an east-west trending ridge) north-eastward into Pleasant Valley. The fault was also shown by Page (1963). Subsequent work by Ventura County (1975) does not extend the fault into Pleasant Valley; the Pleasant Valley segment is included, instead, as part of the Bailey fault (see Figure 1; discussed later in this report). The latter (1975) study also discusses the role of the Camarillo fault as a ground water barrier, displacing Recent water-bearing sediments, south side down, by about 200 feet (vertical separation). In Weber and others' (1976) compilation they have apparently used the earlier interpretation, based largely on Bailey's (1951) unpublished work. Although the fault has not been projected to the west, oil field data does show a zone of WNW-trending faults in the Oxnard oil field, at a depth of more than 6000' (California Division of Oil & Gas, 1991). Refer to Figure 1 for oil field location.

Jakes (1979) shows the fault south of the freeway and then bounding the southern side of the hill where Adolfo Camarillo High School is sited, but does not extend the fault eastward. This essentially follows the mapping of Ventura County (1975). Jakes points out that the hill on which the school is sited is probably the eastern continuation of the ridge to the west, having been eroded in between by Calleguas Creek. Both are mapped by Jakes, as well as other workers, as being underlain by older alluvium. Along the trend of the fault, a 10-foot high step in the flood plain parallels and underlies the freeway (Blake, 1991). The upper deposits of this flood plain, about one mile to the northeast, are probably Holocene in age (Staal, Gardner & Dunne, 1988; Geolabs-Westlake Village, 1990c; Shlemon, 1990). The soils on this surface, both north and south of the scarp, consist of young loam, loamy sand, and sandy loam with an A/C soil profile (USDA, 1970; see Figure 8 herein).

The Camarillo fault was previously evaluated by Smith (1977c), who found that the fault was not clearly a surface fault nor sufficiently active for zoning. Smith cited Weber and others (1976) incorrectly in two instances, although this did not affect his conclusions. Along the western part of the fault (south of the prominent ridge), Smith indicated two possible "sags" from Weber and others (1976) as suggesting youthful activity, however the original map indicates a modified fault scarp (denoted by an "S") at these two localities. To the east, south of the High School, Smith notes the fault as cutting Saugus Formation. Here, however, Weber and others only showed a conjectural fault along the southern margin of the bedrock knoll. There is no documentation in either reference of an observed fault contact.

Detailed studies along the Camarillo fault have located only subsidiary "bending moment" faults, which are considered to be secondary to the main structure (an inferred high-angle north-dipping reverse fault) that may not reach the surface. Gardner (1982), citing oil well and other data, infers that the fault dips north at approximately 80°. Trenching by Gardner (at the western edge of section 36; see Figure 10) revealed Pleistocene and possibly younger deposits that are locally tilted southward up to 45°. Within these deposits are north- and south-dipping shears with from 1 inch to 6 inches separation, that are interpreted to be "bending moment faults" above the main buried fault (Gardner, 1982; Yeats, 1982). An unpublished investigation south of the 101 freeway near Carmen Drive (in section 35; Geolabs, 1990d; cited by Blake, 1991) revealed south-dipping reverse faults which Blake interpreted as bending-moment faults. On one fault, displacement within the Pleistocene deposits diminished upward, from 25" to 12" within a 6-foot long section of the fault (see Figure 11). Groundwater data from Ventura County (1975) suggested that the fault dies out along the westerly plunging anticline that forms the ridge.

Some studies have had negative results. A recent study by Pacific Materials Laboratory, Inc. (1996) was on a site just south of the inferred fault projection, east of Lewis Road, on Magnolia Street. This site is within the Calleguas Creek flood plain. A subsurface profile, constructed using cone penetrometer data to a depth of 50-55 feet, suggests possible continuity of interpreted units across the site (no trenching was done). In a site study to the east of Camarillo High School, Geolabs-Westlake Village (1988) excavated a series of trenches across the fault projection and observed no evidence of faulting, although the data did not conclusively preclude faulting. The trench logs do show a few (apparently minor?) fractures and zones of caliche.

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

The Camarillo fault is most prominently expressed by the linear southern margin of the east-west anticlinal ridge southwest of Camarillo. The southern slope appears to be rather planar with a relatively abrupt base, as if it were a fault scarp, whereas the northern slope of the ridge is more rounded and less abrupt, reflecting its fold origin. A probable antecedent drainage (now a wind gap) cuts southwest across the ridge in section 35 and is truncated at the scarp.

In the flood plain immediately to the east of the ridge, a small drainage (possibly man-induced) used to cross the projection of this inferred fault (1938 photos AXI-18-95&96). Although no scarp was discernible, the drainage changed from an eroding channel, north of the fault projection, to a depositional drainage to the south. Earlier photos (Fairchild, 1927, C104, K18&K19) indicate a possible scarp or tonal lineament at this location. Continuing eastward, the fault appears to step left (northward) to a gentle, curvilinear bench in the Calleguas Creek flood plain, a bench that is now occupied by the 101 Freeway. Although not visible in the aerial photos, the 1950 topographic base map (1:24,000) reveals the early stages of a fan/levee complex where Calleguas Creek debouches from the step in the flood plain. The north-south elongate nature of this deposit suggests that there has not been sufficient time for it to develop a full fan shape. A somewhat broader, young fan is also suggested by the distribution of soil unit **MeA** on the USDA (1970) soil map (see Figure 8).

East of Calleguas Creek the Camarillo fault may be responsible for the abrupt southern margin of a knob of older alluvium on which Adolfo Camarillo High School is located. This slope, though, does not have the sharp upper slope break that is visible on the ridge to the west. This slope may also have been erosionally enhanced by Conejo Creek in the past. The surface of this knob is inclined northward and may reflect tilting. The escarpment died out (prior to recent grading) east of Santa Rosa Road.

There is no expression, geomorphic or tonal, detectable in the presumed Holocene flood plains to the west of Camarillo or to the east of the high school scarp.

Field Observations (Figure 4)

Much of the surface expression of this inferred fault is modified by agricultural, residential or commercial development. As indicated above, US 101 now sits atop the step in the Calleguas Creek flood plain, but the step is perhaps more apparent because of this.

Grading for new development near the western end of the prominent ridge south of the freeway was underway during my field reconnaissance in May and June of 1996. The axis of the anticline that underlies this ridge was evident in the cut slope east of the graded area and in a sewer trench. Cross-bedded late-Pleistocene sands just south of the anticlinal axis dip about 10° to the south. In a limited exposure closer to the escarpment, behind greenhouses to the southeast, Saugus Formation and the overlying fluvial deposits both dip southward 53° with a strike of N83°W. The Saugus Formation included various slickensided shears with steeper dips (south) and about the same strike as the bedding. Also observed here (southwest of the antecedent drainage) was a steeply dipping north/south-oriented shear.

To the east, at Adolfo Camarillo High School, exposures were poor, but there was a suggestion of nearly horizontal bedding to the north of the scarp. There are no exposures to verify the inferred fault as shown by Weber and others (1976).

Discussion and Conclusions

Based on groundwater and oil well data, it appears that the interpreted Camarillo fault is a real structure. The significant questions for this study are: is it active? and is it a surface fault? Limited trenching has not found a main fault trace, however, the straight planar nature of most of the escarpment southwest of Camarillo strongly suggests that there is a surface fault, as does the steepening of the bedding toward the base of the slope. Alternatively, the southern slope might have been produced by stream erosion, but the drainage in this area is generally to the south or southwest and it seems unlikely that a drainage would run east-west (even the Calleguas Creek fan margin), cutting the southern base of a slope for such a distance. To the west the fault appears to merge into and be buried beneath a less abrupt fold. To the east, the gentle scarp across the Calleguas Creek flood plain could be a monoclinal warp above a buried fault. The lower margin of the slope, though, appears as if it may have been more abrupt, perhaps reflecting a fault that flattens out at a shallow depth within the younger alluvial deposits. The trench logs from the Geolabs (1988) study east of the high school show no faulting, but an irregular contact in T-1 and relatively massive silty sandstone in T-2 could conceal minor faulting at the eastern end of the Camarillo fault. Active faulting may step northward at this point and continue eastward along the inferred "Santa Rosa Valley fault".

Although there is no hard evidence of Holocene activity on this fault, the step in the Calleguas Creek flood plain would appear to be Holocene based on the inferred age of the flood plain deposits and the apparent youth of the fan developing below the step. Studies for Pitts Ranch and St. John's Seminary, about one mile to the northeast (Staal, Gardner & Dunne, 1988; Geolabs-Westlake Village, 1990c; Shlemon, 1990), explored the alluvial deposits of this flood plain and judged that the deposits were Holocene to several meters depth (Figure 2, locality T-6). The flood plain at the step is continuous with the Calleguas Creek flood plain to the north and the step must therefore also be Holocene. Considering the relationship of this fault to other active faults in this zone it is reasonable to interpret it as an active fault, as well.

SPRINGVILLE FAULT

Summary of Available Data (Figure 2)

The Springville fault marks the sinuous southern margin of the Camarillo Hills, which are largely the surface expression of the **Camarillo anticline** (terminology of Mukae and Turner, 1975). This fold was called the Camarillo Hills anticline by Jakes (1979) and the Las Posas anticline by Weber and others (1973). A smaller *en echelon* fold to the southwest is called the Springville Dome by Jakes (1979) and the **Springville anticline** by Mukae and Turner (1975), but was referred to as the "Las Posas anticline" by Leighton & Associates (1993). My preference is to follow Mukae and Turner (1975) who in turn followed the earlier nomenclature established by the State Water Resources Board (1956) and these names are indicated in **bold** (see Figure 1 for regional fold and fault terminology). These folds are relatively young, having developed within the past few hundred-thousand years (McMillan and others, 1991). The folds are developing above the young thrust faults of the Springville fault zone, which may be a backthrust off of the Oak Ridge fault (Whitney & Gath, 1991).

The fault zone was first mapped by Bailey (1951), but the first published map of this fault was by State Water Resources Board (1956). It was shown as a single (southern) trace by Page (1963). Mukae and Turner (1975) suggested that the Springville fault may actually consist of two or more *en echelon* segments. One prominent segment (southern trace) defines the southern margin of the Springville anticline and the other prominent segment (northern trace) extends along the southern margin of the Camarillo anticline. Dibblee and Ehrenspeck (1990) show only one concealed trace that closely follows the base of the hills. Turner (1975) interpreted as much as 250 feet of vertical displacement of the Pleistocene Fox Canyon aquifer (within the Saugus Formation) across the fault zone. The fault zone is accompanied by backthrusts, normal faults, and tear faults within the hills and associated subsidiary folds (Kile and others, 1991; McMillan and others, 1991; Whitney and Gath, 1991). This fault zone was previously evaluated by Smith (1977b) who found (at that time) that there was no evidence for Holocene displacement.

The **southern trace**, largely concealed, has been mapped from north of Springville, where it lies at the base of the hills (formed by the Springville anticline) and then projects eastward, under the alluvium, set out from the hills (Pasta, 1958; Jakes, 1979; see Figure 2). A map by Turner (1975), depicting the base of the groundwater reservoir, suggests that the fault may veer northeastward and be truncated against the northern strand between projected sections 23 and 24. Jakes (1979) stated that there is no subsurface indication of the fault to the west of the Springville anticline, based on oil and groundwater data. Although more recent data from the Santa Clara Avenue oil field (California Division of Oil and Gas, 1991) indicates the possibility of deep (-7000') faulting, there is no indication that this structure approaches the surface. See Figure 1 for oil field location.

Two geotechnical studies have explored a portion of the southern trace near its western end. Kile and others (1991) described a 4-10' scarp along the fault, with an elevated colluvial terrace. Their trenches revealed one to two faults, at or above the toe of slope, with a strike of N85°E to N85°W and dipping 13°-18°N. Additional trenching and analysis in the same area by Leighton & Associates (1993; also Whitney and Gath, 1991, and Gonzalez and Rockwell, 1991) further clarified the nature of faulting associated with the Springville anticline. They identified five styles of faulting, three of them inactive. The two active fault styles are the main north-dipping thrust along the southern margin of the Springville anticline and some lesser south-dipping backthrusts off of the main thrust. The southern trace of the Springville fault consists of two active *en echelon* segments (western and eastern) on their project site. Although the faults flatten out as they approach the surface, they are observable within trenching depths. Faulted sediments in trench LT-6 have MRT[1] dates ranging from 5,420±120 to 7,810±140 years as reported by Leighton & Associates (1993, p.17). They interpreted their data to suggest that typical displacement per event is about 0.6-1.1 m with an average recurrence interval of about 900 years. The latest ground rupture was estimated to have occurred roughly 600±500 years ago, based on the difference in MRT ages between the modern,

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1 ^{14}C mean residence time - this is an average age of soil carbon present and is usually about one-half of the true age of the soil horizon. Actual relationship between MRT age and true age varies, as discussed by Wang and others (1996).

active soil and its buried equivalent, under the lip of the thrust fault[2]. Gonzalez and Rockwell (1991) reported from 7-12m displacement of a late-Pleistocene channel deposit and estimated a slip rate of 0.5-0.9 mm/yr. A trench study by Geolabs-Westlake Village (1991), northeast of Earl Joseph Drive and Green Lawn Avenue, found a south-verging low-angle thrust (within Pleistocene San Pedro Formation) that may have been a minor splay of the Springville fault. The presumed concealed portion of the fault, to the east, has a subsurface dip ranging from 55°N (at 2530' below sea level) to 78°N (at 5150' below sea level)(oil well data cited by Jakes, 1979) and shows several hundred feet of vertical displacement. A fault study, utilizing auger borings (Buena Engineers, 1972), found that a shell bed (240ka) at a depth of 25' was not present (within the 50'-60' depth of the borings) to the south of the interpreted fault, suggesting at least 25' of displacement. Near the eastern end of the fault zone, just west of the Calleguas Creek flood plain, two studies along the southern front of the Camarillo Hills (Tierra Tech, 1983; Westland Geological Services, 1987b) found no evidence of faulting as shown by previous workers (Figure 2).

Among the backthrusts investigated by Leighton & Associates (1993), the most prominent is the "Reservoir fault" with as much as 145 feet of vertical offset (drag folding included). This fault was determined to not be active, based on soil stratigraphy and structural interpretation. The Reservoir fault was modeled as an intercalation backthrust (see Figure 3) that ceased to be active once the Springville fault broke past it, about 30,000 years ago. The youngest unit offset by the Reservoir fault is a paleosol that is about 32,000 years old. An argument is presented that this subsidiary fault has not responded to at least 10 subsequent events on the Springville fault (Leighton & Assoc., 1993), although the number of events may be half this amount. Lesser backthrusts behind the main trace, yet well south of the Reservoir fault, are younger, having formed as the Springville fault propagated to the south. Leighton & Associates (1993) determined that the minor backthrust above their western *en echelon* fault segment was no longer active but that the backthrusts above their eastern *en echelon* segment are still active (or reactivated).

Inactive faults found by Leighton & Associates (1993) (not shown on Figure 2) include older faults within the Saugus Formation (a) that are attributed by them to dewatering and liquefaction phenomena, normal faults (b) along the crest of the anticline, and NE and NW trending strike-slip faults (c) in the anticlinal crest area.

(a) The older faults within the Saugus Formation occurred while the formation was still relatively undeformed and saturated.

(b) The normal faults are attributed by Leighton & Associates (1993) to a bending-moment mechanism related to the folding of the anticline. This flexure is postulated to have ceased once the thrust fault propagated to the surface. As logged in several trenches, these faults do not displace late-Pleistocene soils.

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[2] Trench LT-6 exposed a section that included several paleosols that had been over-ridden by the thrust fault. The modern soil yielded an MRT date of 5,420±120ybp in it's lower section. Immediately to the north, this same soil section had been over-ridden by the Springville fault, presumably cutting off the source for young carbon to the now-buried soil. The MRT date at this buried locality was 6,020±100ybp. While the MRT age of the unburied soil continued to get younger, as new carbon was incorporated into the soil, the buried section began to age normally. Leighton and Associates interpreted that the difference in these two ages, within the same soil unit, indicated the time elapsed since faulting had thrust over the buried section.

(c) The strike-slip faults are interpreted to be tear faults accommodating a partially daylighted thrust. Once the entire thrust daylighted these faults would become inactive. Trench observations indicate that most of these tear faults do not displace late-Pleistocene to Holocene soils. Holocene displacement could not be precluded on one tear fault, although there was no evidence for such displacement.

The **northern trace** of the Springville fault lies along the base of the main body of the Camarillo Hills and marks the southern margin of the Camarillo anticline. At its western end it merges into the Springville anticline (or perhaps its northern flank) and at its eastern end it disappears within the water gap of Calleguas Creek. Jakes (1979) proposed two models for this fault strand: either a shallowly north-dipping fault (18°) or a steeply north-dipping reverse fault. Several studies (see Figure 2) have looked at surface faulting along this trace (Dale Glenn & Associates, 1987; Petra Geotechnical, 1990; Westland Geological Services, 1987a,b & 1989). The most telling of these studies was by Petra Geotechnical (summarized by Ruff and Shlemon, 1991) who found that a shallowly north-dipping fault, striking N25°E to N45°E, thrust bedrock over colluvium. They concluded that the fault was probably active based on the offset colluvium (presumed Holocene) and thickening of younger (Holocene) slopewash deposits. They also observed a zone of reverse and normal faults upslope of the main fault that they judged to be secondary faults to the main trace. The 1989 study just to the west, by Westland Geological Services, found a south-dipping reverse fault within a prominent sidehill bench (marked *lt* on Figure 4). Striking N65°E to N75°E and dipping 45°-55°S, this probable backthrust is accompanied by prominent drag folding. Two other studies (Dale Glenn & Assoc., 1987 and Westland Geological Services, 1987a) found probable secondary faulting and could not demonstrate presence or lack of Holocene movement. The faults observed, however, are not trivial shears as one had an 8-foot thick crush zone and caused drag of the adjacent Pleistocene (Saugus Formation) bedrock (Glenn, 1991).

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

The inferred strands of the Springville fault zone are generally marked in the topography by a relatively abrupt, curvilinear break in slope along the southern margin of the Camarillo Hills. A left-step in this front indicates the *en echelon* expression of the southern and northern strands. Faceted spurs and linear scarps are locally prominent. Even where the main fault may not reach the surface, linear troughs, drainages, aligned saddles, and sidehill benches suggest the presence of local backthrusts off the frontal thrust, particularly along the western part of the fault zone.

Along the westernmost portion of the fault zone, where the south margin of the Springville anticline is controlled by the south strand of the fault, south-flowing canyons are incised into the hills north of the fault, but do not incise their fans south of the fault. This suggests either a high rate of erosion, or else uplift along the fault has kept the canyons from lowering their base level. Although recently rejuvenated, the erosion does not look sufficient for the former explanation, and high rates of erosion would tend to fill the mouths of the canyons. Instead, scarps and faceted spurs indicate the activity of this segment. A line of alluvial scarps and tonal contrasts suggests an eastern projection of this fault, south of Las Posas Road.

Where the front steps north, to the northern strand, prominent scarps and facets suggest significant displacement, however incision of the drainages across the fault trace suggest that activity may not be as recent or else the slip-rate is lower. To the east, greater erosion of the hills above the fault has resulted in more significant fan development, with little incision south of the fault. The higher erosion rates coincide roughly with the marine sands of the Las Posas Formation (lithology per Dibblee and Ehrenspeck, 1990). Fan incision does appear to stop, perhaps coincidentally, at the projection of the buried southern fault strand of Pasta (1958) and Jakes(1979). However, there is no indication in the aerial photos inspected of any abrupt slope break.

The expression of the fault along the front presents some notable contrasts. There are segments to the west that are not as well defined and which tend to be accompanied by more prominent troughs and benches in the hills behind (e.g. north of the secs. 26/27 boundary). This suggests that locally the fault is intercalated in the sediments and has a more active backthrust component than other areas where scarps indicate a more prominent surface displacement.

Field Observations (Figure 4)

Although there are no natural exposures of the Springville fault and there has been much development along the fault zone, the general geomorphic escarpment is still quite apparent. The landform suggests that the northern trace lies beneath or just south of North Loop Drive, and jointing in the bedrock dips steeply to the south in this area. Along the general trend of the southern (concealed) trace, in projected section 24, there is a distinct rise visible in several of the north-south streets. However, reference to grading plans for tract 2418 (on file with the City of Camarillo) shows that this feature is an artifact of grading.

Discussion and Conclusions

The western end of the southern trace appears to be a Holocene active fault, based on studies by Leighton & Associates (1993). However, the age of latest fault rupture may be older than estimated by the consultants because the MRT ages do not represent the full age of the soil units sampled. Due to uncertainties in the interpretation of soil carbon/MRT dates (Wang and others, 1996) the actual time intervals may be more than double the consultant's estimates. The last event was more likely at least 1200 years ago, rather than the 600 years reported, and prior events similarly may have been more than twice the estimated ages. Although the slip-rate may be lower than estimated (with a longer recurrence interval), the data still indicate a Holocene age for faulting. Activity would appear to step left to the northern trace, beginning at about Las Posas Road. Eastward, yet diminishing, activity of the southern trace would account for the low scarps and incision of the streams upslope of the southern trace. There is no evidence for activity on the concealed trace identified by Buena Engineers (1972). The northern trace has been found to be probably active by Petra Geotechnical (1990; also Ruff and Shlemon, 1991). Continuity and extent of these two fault traces is fairly well established by the prominence of scarps and faceted spurs. Although some short segments of the fault zone appear to be blind (being intercalated in the shallow sediments), with active backthrusts, the fault can be considered to be essentially a surface fault.

Leighton & Associates (1993) have presented reasonable evidence and interpretations to conclude that the Reservoir fault is not active. However, other backthrusts closer to the active front probably are active, or can be reactivated by slope failures above the active front. As discussed by Leighton & Associates (1993, p.13), the activity of the fault zone can fluctuate between the main thrust and the lesser backthrusts.

"WRIGHT ROAD FAULT"

Summary of Available Data (Figure 2)

Robert Whitney[3] has postulated a tear fault at the western end of the Camarillo anticline, separating this structure from the Oxnard Plain to the west (Price and Whitney, 1992; Leighton & Associates, 1993; Whitney and Gath, 1994). He has called this fault the "Wright Road fault" after its most prominent scarp across Wright Road. There has been no surface or subsurface work performed to specifically assess this structure.

The postulated fault corresponds roughly with the eastern margin of the Holocene Oxnard aquifer, however there is no suggestion in the literature of a fault-controlled boundary (State Water Resources Board, 1956; Mukae and Turner, 1975; Turner, 1975). A cross-section by Ventura County (1975, section B-B') shows what appears to be a buttress unconformity for the Oxnard aquifer at this boundary, with lower units being folded or inclined down to the west. A soil survey (USDA, 1970) shows the distribution of soil types across the inferred fault zone (see Figure 9).

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

This postulated fault is indicated by a distinct alignment of several low escarpments with an arcuate tonal lineament across an intervening flood plain. The lineament is indicated variously by a dark tonal line, a tonal contrast in the soil, or a contrast in apparent health or growth of orchard trees. Although most of the low scarps mark the edge of an elevated older alluvial surface, at least one low scarp (crossing Wright Road) is across a younger fan surface associated with Beardsley Wash. Within this younger surface, tonal features suggest that a buried or infilled channel appears to be truncated against the arcuate lineament. Another small scarp is visible (1938, 1947 and 1953 photos) part-way across alluvium at the mouth of a drainage at the north end of the fault's expression.

It is important to note that the arcuate tonal lineament is visible in the 1938 aerial photos, prior to the establishment of well-defined agricultural field boundaries in this area. Later field boundaries, and accompanying irrigation lines, follow part of the lineament at the southern edge of the Santa Paula quadrangle.

It is also evident from the aerial photos as well as from the topographic map that Beardsley Wash is incised east of the fault, but forms a fan to the southwest. This fan is also suggested by map unit **SwC** on the soil survey map (USDA, 1970; Figure 9 herein).

Field Observations (Figure 4)

Although the escarpment is generally visible, no exposures of the fault were observed. The scarp at Wright Road (~2m) is still apparent as one drives across it. Just north of the quadrangle boundary, the tonal lineament crosses a drainage ditch at a point where there is currently a concrete box and partly-abandoned buried concrete irrigation line. A resident on the ranch suggested that a petroleum pipeline may be buried there, however, several foot-traverses across the lineament with a sensitive metal detector found no indication of a buried metal pipeline, at least within the upper 5-15

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[3] geologist, previously with Leighton & Associates

feet. The scarp southeast of Beardsley Road is still visible as a broad, gentle warp (~2m high) between the upper and lower surfaces. It was more distinct in older aerial photos and has probably been subdued somewhat by annual cultivation.

Discussion and Conclusions

On a larger scale, the "Wright Road fault" may be just the most obvious evidence of a structural boundary separating the Ventura Avenue anticline on the west from South Mountain, the Oak Ridge fault and the Camarillo anticline on the east. Figure 1 shows these general relations. The idea of a structural boundary (or domain boundary) of this sort goes back to Yeats and others (1988) and is discussed more recently by Huftile and Yeats (1995).

The interpretation of the "Wright Road fault" as a tear fault terminating the west end of the Camarillo and Springville anticlines is reasonable. However, it may just be the most recently active such feature. Although the anticlinal hills appear truncated, groundwater data suggest that the fold structure may continue within the pre-Holocene sediments at least one to two more miles westward beneath the Holocene floodplain. No fault was interpreted at the eastern margin of the Oxnard aquifer in the original study (Ventura County, 1975), nor in the underlying Pleistocene aquifers, and an interpretation, consistent with the data, is that the upper aquifers were deposited against a late-Pleistocene--Holocene shoreline. The data could also allow a fault interpretation, with recent folding continuing to the east of the fault. The "Wright Road fault", then, would represent an eastern shift in the deformational boundary.

Near its northern and southern defined limits (Figures 4 and 9), the inferred fault marks a separation between an uplifted (up to 75') older surface to the east and the more modern flood plain to the west. The separated surfaces are clearly different ages. The soils on the upper surface (units **RcC**, **RcE$_2$**, and **HuB**) have a well-developed B horizon and a calcic horizon, whereas the surface below (units **Cc**, **Cd**, **SaC**, and **SwC**) has an A/C profile (USDA, 1970). The height of the scarp is greatest to the north where tectonic uplift may have been greatest, somewhat less to the south, and is at a minimum in the intervening valley. As an alternative hypothesis to faulting, the scarp could be an old sea cliff/shoreline or a lateral stream cut from a southward meandering Santa Clara River, planing across the nose of the folds.

Some of the most convincing evidence for faulting lies in the vicinity of Wright Road. Whereas the clearest scarps to the north and south separate surfaces of contrasting age, at Wright Road there is a lesser scarp, or warp, across an otherwise continuous younger alluvial surface. The soil survey (USDA, 1970; see Figure 9) shows that the soil on this surface (unit **CyA**) has an A/C profile, indicating relative youth. The scarp is shown in the soil survey as a band of 2%-9% slope (unit **CyC**). The soil survey map also suggests a fan of younger alluvium (soil unit **SwC**) forming where Beardsley Wash crosses the fault. Also suggestive of youthful faulting is the arcuate tonal lineament continuing north of Wright Road within soil unit **CyA**, as well as within an apparently younger soil (**SaC**). This feature is visible in all photos reviewed. It looks like a fault-related shallow groundwater barrier, including possible damming of an older infilled channel. Orchard trees also appear to be healthier (in the aerial photos) upstream of the lineament. The alluvial scarp and lineament are not consistent with a shoreline or meander cut because they appear in a surface that would post-date such erosional cutting. Also, the scarps and lineaments have an overlapping *en echelon* pattern that would not be as likely to form from lateral erosion. A fault interpretation is also strongly supported by a small yet distinct scarp that appears to affect younger alluvium (A/C soil profile per USDA, 1970) at the northern end of the fault.

The possibility that the arcuate tonal lineament was related to a pipeline was given careful consideration. A concrete irrigation pipe would not be detected by the metal detector used in the field reconnaissance, and leakage from such a pipe could cause the dark tonal lineament. Although a concrete box was observed where the lineament crosses a local drainage ditch, and although an obvious irrigation system follows the lineament north from this point, the existence of the lineament in 1938, prior to establishment of the current field usage and outlines suggests that this is coincidence. It would be unlikely that a pipeline would follow a curved pattern across open terrain and remain in place after orchard patterns developed across the feature. Also, a pipeline would not explain the local tonal contrasts and suggestion of a groundwater barrier.

Without exposures to prove faulting, I slightly (65%-35%) favor a fault explanation for these features over a non-fault explanation. Accepting it as a fault, it is well defined. Its expression within probable Holocene alluvium, north of Wright Road suggests that it is an active, near-surface feature.

"SANTA ROSA VALLEY FAULT"

Summary of Available Data (Figure 2)

The proposed "Santa Rosa Valley fault" (new name informally introduced here) extends eastward from the Calleguas Creek flood plain, about one half-mile north of Camarillo High School, and then along the medial part of Pleasant Valley and Santa Rosa Valley, on the adjacent Newbury Park quadrangle (Figures 1 and 2). This inferred structure has also been referred to as the "Santa Rosa Road Fold/Fault System" by Boales (1991). Segments of this fault were shown previously by Weber and others (1975).

A study by Geolabs-Westlake Village (1990a) across the trend of this inferred fault, near the eastern edge of the Camarillo quadrangle, found no evidence of surface faulting. Farther east, on the adjacent Newbury Park quadrangle, studies cited by Jakes (1979)[4] identified a steeply dipping, east-west trending fault or fault zone along Santa Rosa Road. Also, in this vicinity, Thomas Blake (personal communication, 1997) observed a north-dipping fault at the bottom of a 22'-deep excavation. I infer these localities to be along the continued eastern extent of the "Santa Rosa Valley fault".

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

The most compelling evidence for this fault as a surface feature is a distinct scarp, across and east of Calleguas Creek, that is visible in older aerial photography (USDA,1938, 1952; USGS, 1947). This scarp has been obliterated by subsequent development of the Rancho Adolfo mobile-home park (between Adolfo Road and Calleguas Creek). The scarp separates two relatively level surfaces to the north and south. The topography on the grading plan for the mobile home park

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[4] Jakes cites a study by Buena Engineers, Inc. (1988)

indicates that prior to grading there was a 15'-high escarpment that was approximately 120' wide, making it a distinct, but not sharp, feature. (That map is on file with the City of Camarillo. At the time of the mobile-home park development this escarpment was not investigated for possible faulting.) The fact that the scarp appears much sharper in the aerial photography than is represented on the grading plan may be explainable by agricultural land-use prior to development. Immediately to the east, where the fault projects along the base of a hillslope, an older north-south trending channel-cut projects north directly into the hillslope, suggesting 100'-150' of left-lateral displacement. The channel cut is not well defined north of the scarp, probably because the stream was better able to cut a vertical bank in the Pleistocene alluvial deposits to the south. The nearly right-angle juncture of the scarp with the paleo-stream bank argues against an erosional origin for the scarp. This is in contrast to the more obvious, curving meander cut one mile to the west. These geomorphic relations typify fault/stream bank offsets as illustrated in Figure 6 (after McCalpin, 1987).

To the east, on the Newbury Park quadrangle, this inferred fault is expressed by a distinct uplift of the valley floor, north of Las Posas Road. The uplift gives the impression of a series of right-stepping *en echelon* monoclinal folds (Figure 7), and has forced the drainage to run along the southern margin of the Santa Rosa Valley.

A possible extension of this uplift to the west is a low knoll west of the Southern Pacific railroad tracks and north of the Camarillo fault. An abandoned meander cut from Calleguas Creek lies immediately south of this knoll. A line of very weak tonal lineaments, visible only in the 1947 photographs, projects from the well defined scarp, east of Calleguas Creek, westward toward this knoll. That this weak lineament appears in only one photo set raises the possibility that it is an artifact of human activity.

Field Observations (Figure 4)

The once-prominent scarp has been obliterated by grading for a trailer park, although the general rise in ground is still visible. The escarpment to the east is still apparent behind various housing developments and along Santa Rosa Road.

Discussion and Conclusions

Interpretation of older aerial photos and soil survey data (USDA, 1970) provides reasonable evidence for a Holocene surface fault immediately east of Calleguas Creek. The similar soils (**AnC**, **MoA**, **PcA**, and **SwA** - all Calcic Haploxerolls) above and below the scarp as well as west of Calleguas Creek suggest that these were once continuous flood plain deposits that have been offset across the fault[5]. These younger deposits (with an A/C soil profile) are essentially continuous with the deposits to the north that are considered to be Holocene by Geolabs (1990c) and Shlemon (1990). Another surface, to the east of an older stream cut and south of the fault, although at about the same elevation as the upper surface to the northwest, has a much more strongly developed soil profile (**HuC2** includes a well-developed B horizon), compared to the major surfaces west of the stream cut (**MoA** and **PcA**) which have a much younger A/C soil profile. A few remnants of older flood plain

[5] Ken Oster, soil scientist with the U.S.D.A. Natural Resources Conservation Service, comments that PcA and SwA share many characteristics, and may be the same surface (written communication, 9/10/95)

deposits (**HuB**, **HuE3**, **RcC** and **RcE2**, all with A/B/C soil profiles) persist north of the fault and east of Calleguas Creek. These remnants are higher than the younger flood plain deposits.

The roughly 15' elevation change across the inferred fault scarp provides a measure of the vertical component of displacement and the older stream bank suggests left-lateral displacement that is several times the vertical displacement. The fault apparently diminishes in offset west of Calleguas Creek so that offset of the flood plain is not apparent. The low knoll west of the railroad tracks may be related to this fault, although the southern edge of the knoll has obviously been erosionally modified. The Camarillo fault may be a left-stepping westward continuation of this fault.

To the east, the fault appears to be more deeply buried, resulting in only the more gentle surface folding suggested by the topography. Although not a part of this limited evaluation, the structural zone appears to extend eastward on the Newbury Park quadrangle (see Figure 7). Topographic analysis suggests that the fault zone may continue as a buried fault causing a series of right-stepping *en echelon* folds. This area should be further evaluated when time and resources are available.

SANTA ROSA FAULT

Summary of Available Data (Figure 2)

The Santa Rosa fault was labeled the Santa Rosa fault zone by the State Water Resources Board (1953, Plate B-1C) and is generally considered continuous with the Simi fault to the east. The name, Santa Rosa fault is generally reserved for the portion of the fault zone in the Santa Rosa Valley. It is mapped as the Santa Rosa fault along the northern margin of Pleasant Valley (on the Newbury Park quadrangle) by Weber and others (1973), and is mapped as part of the Simi fault zone, in the same location, by Weber and others (1976). In these two publications, Weber and his co-workers showed two traces of the fault zone, merging westward into a concealed trace on the Camarillo quadrangle, apparently based on mapping by Pasta (1958). Pasta called the northern trace the Kew Quarry fault. Jakes (1979) further evaluated the concealed trace, in identifying her "Camarillo Valley Lineation". She observed no definite subsurface evidence for a fault, and offered an alternate explanation of the lineament as being the margin of a floodplain. The Santa Rosa fault was previously evaluated (as part of the Simi fault) by Smith (1977a), who concluded at that time that although well-defined there was insufficient evidence to show that the fault was active.

Studies, on the Camarillo quadrangle, by Staal, Gardner, & Dunne (1988) and by Geolabs (1990c), for Pitts Ranch, found no evidence for Holocene activity on this fault zone as projected across the flood plain deposits of Calleguas Creek. Staal, Gardner, & Dunne focused on the southern part of the property, while Geolabs focused on the northern portion of the property. They used a combination of seismic reflection surveys, cone penetrometer tests (CPT), borings and limited backhoe trenches to show that, although there may be faulting (unconfirmed) within the Pleistocene Saugus Formation (suggested by seismic surveys), there was no obvious displacement of the Holocene deposits. The data did not conclusively preclude Holocene faulting, but did find relative continuity of a presumed 12,000 to 15,000 year old unconformity. Although two zones of faulting and deformation have been identified to the east (on the Newbury Park quadrangle), the studies often indicated blind faulting and do not provide evidence for Holocene surface displacement (various studies cited by Blake, 1991).

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

The Santa Rosa fault has no expression on the Camarillo quadrangle. The Camarillo Valley Lineation appears to mark the lower limit of south-draining fans from the Camarillo Hills as they are truncated by a westward-draining portion of the Calleguas Creek floodplain (as suggested by Jakes, 1979). On the adjacent Newbury Park quadrangle the southern strand of this fault zone apparently marks the break between the Las Posas Hills and the southerly adjacent upland elevated by the Santa Rosa Valley fault. The northern strand may define the north side of an east-west trending ridge.

Field Observations (Figure 4)

No field observations were made of this fault zone within the Camarillo quadrangle. Reconnaissance verified the slope break along Upland Road on the adjacent Newbury Park quadrangle.

Discussion and Conclusions

There is insufficient evidence to establish zoning of the Santa Rosa fault as it is neither well-defined nor sufficiently active on the Camarillo quadrangle. This fault and its relationship to the Santa Rosa Valley fault and the Simi fault, to the east, should be evaluated when time and resources are available.

OTHER FAULTS

Summary of Available Data (Figures 1 & 2)

The Bailey fault (shown but not named by Bailey, 1951), although displacing older water-bearing sediments, apparently does not affect the upper-Pleistocene Mugu aquifer zone or the Holocene Oxnard aquifer (Mukae & Turner, 1975, cross-section A-A').

The Somis fault is a northeast-trending fault, separating the Camarillo Hills from the Las Posas Hills, that was first mapped by Bailey (1951). It is a high-angle fault that has probably had left-lateral displacement, but does not displace Saugus Formation (Jakes, 1979).

The possibility of several additional faults was also considered in this FER. Although no fault has been mapped, the north margin of the Camarillo Hills looks very similar to their southern margin, where the Springville fault has been mapped. Part of the northern margin of the Camarillo Hills was investigated by Gorian & Associates (1989), but their investigation focused on slope stability and did not explore the base of the slope.

Aerial Photo Interpretation (Figure 4; photos used are listed on p.17)

The Bailey and Somis faults have no geomorphic expression.

Although the northern margin of the Springville anticline and the Camarillo Hills bear some resemblance to the southern fault-controlled margin, the northern slopes lack the abruptly incised streams of the southern front. Although canyons are incised above the slope base, these canyons generally taper out at the bottom, reflecting erosion from the mid- and upper-slope region as the anticlines have grown. The smoothly curvilinear margin of the hills gives the impression of fault control, but may merely reflect bedding control on erosion from south- and west-flowing drainages that impinge on the hills. Some unusual sidehill benches in the vicinity of Center School Road are suggestive of faults or backthrusts, but may also be controlled by bedding. Bedding control is indicated by subtle tonal or vegetation contrasts, even where topographic benches are lacking.

Field Observations (Figure 4)

No field observations were made along the concealed Bailey and Somis faults.

Reconnaissance along the northern margin of the Camarillo Hills found no data to supplement the aerial photo interpretation.

Discussion and Conclusions

Data and other studies indicate that the Bailey and Somis faults are not Holocene active structures, nor are they well-defined as surface features. There is no compelling evidence to support a fault interpretation for the northern margin of the Camarillo Hills.

SEISMICITY

Simila and Armand (1991) state that "the seismic activity along the [Simi] fault system is in response to a N-S compressive stress system," however, the zone "is characterized by a very low level of activity." A plot of seismicity from 1932 to 1989 is included as Figure 5. There has been no activity that can be associated with the western end of this fault system with any certainty. An earthquake of M2.5 in 1971 was a thrust earthquake, probably associated with the Oak Ridge fault. Scattered seismicity south of the Camarillo fault, likewise, is probably not associated with the subject faults.

RECOMMENDATIONS

(Refer to Figure 12)

Camarillo Fault:

Based on its apparent Holocene age and probable surface rupture potential this fault should be zoned. I recommend zoning the well-defined fault segments from Las Posas Road on the west to just past Santa Rosa Road on the east. Fault location is based on Dibblee & Ehrenspeck (1990), with data from Weber and others (1976) at the eastern end, and aerial photo interpretation for this FER.

Springville Fault:

Based on documented Holocene activity on at least one, and perhaps both, of the two *en echelon* fault traces, and the well-defined character of the faults, the north and south branches of this fault should be zoned. I recommend zoning the southern trace from the Rancho Las Posas boundary, at its western end, into section 26 at its eastern end. The northern trace should be zoned from the bend in Las Posas Road eastward to the flood plain of Calleguas Creek. Minor backthrusts of the southern and northern traces should be included, but not the Reservoir Fault.

Zoning for the southern trace, west of Las Posas Road, is based principally on the fault traces of Kile and others (1991), Leighton and Associates (1993), and Dibblee & Ehrenspeck (1990). Zoning at and east of Las Posas Road is from aerial photo interpretation for this FER. Zoning of the northern trace is based mainly on the mapping of Dibblee & Ehrenspeck (1990) and aerial photo interpretation for this FER. The eastern end of the zone relies also on mapping by Pasta (1958).

"Wright Road Fault":

The weight of the evidence leans toward an active fault interpretation for this feature. The scarp and tonal features across a relatively young surface (A/C soil profile per USDA, 1970) suggest that this is a Holocene feature. The fault should be zoned for its entire mapped length. Zoning is based entirely on aerial photo interpretation for this FER.

"Santa Rosa Valley Fault":

I recommend zoning the well-defined portion of the fault from Calleguas Creek to Mission Oaks Blvd. The fault has not yet been fully evaluated to the east, on the Newbury Park quadrangle, and additional zoning may be warranted in the future. Zoning is based on aerial photo interpretation for this FER.

Santa Rosa Fault:

The Santa Rosa fault should not be zoned on the Camarillo quadrangle. Zoning to the east may be warranted based on future evaluation.

Report reviewed and approved 10/2/97
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EG 1035

AERIAL PHOTOGRAPHS USED

Fairchild Aerial Surveys -- flight C104 -- scale: 1"=1500' -- b/w

frames K18 & K19	1927

Pacific Western Aerial Surveys -- flight PW VEN -- scale: 1"=2000' -- color

6-85 to 6-89	10/10/88
6-115 to 6-118	9/29/88

U.S. Department of Agriculture -- scale: 1"=1800'± -- b/w

AXI-18-91 to 18-99	5/9/38
AXI-19-6 to 19-24	5/9/38
AXI-19-49 to 19-65	5/9/38
AXI-43-4 to 43-12	6/4/38

AXI-1K-35 to 1K-39	12/13/52
AXI-1K-77 to 1K-81	12/13/52
AXI-3K-101 to 3K-105	01/03/53
AXI-3K-116 to 3K-120	01/03/53
AXI-3K-147 to 3K-151	01/03/53
AXI-3K-168 to 3K-169	01/03/53

U.S. Geological Survey -- flight USGS-EM -- scale: 1"=2000' -- b/w

1-60 to 1-68	8/15/47
1-82 to 1-89	8/15/47
5-67 to 5-74	8/20/47
7-03 to 7-09	8/24/47

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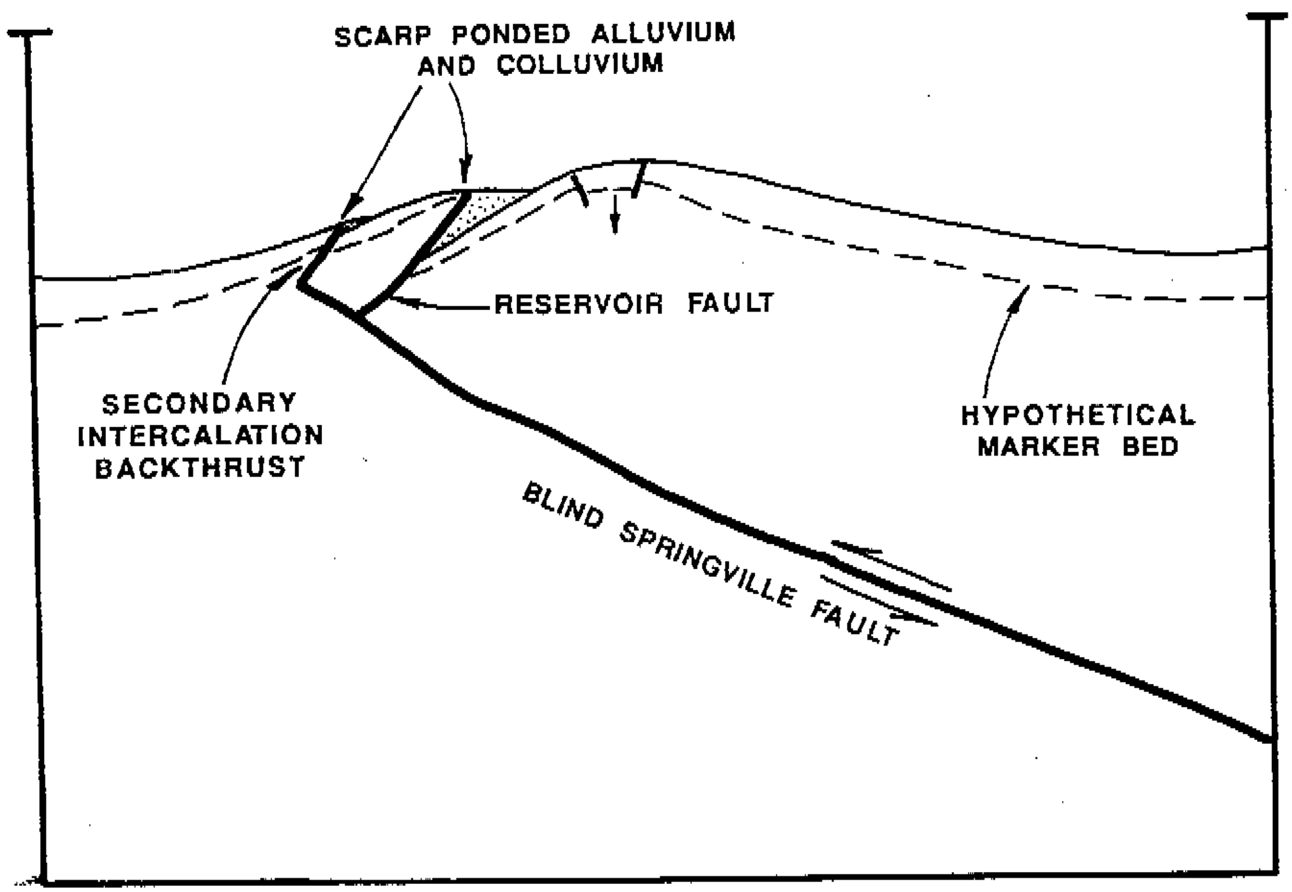


Figure 3 (FER-237) - Illustration of an "intercalation backthrust" wherein the thrust front has intercalated, or inserted, itself between layers of colluvium and bedrock. The uplifted portion of colluvium and bedrock lies above the backthrust. *(Illustration from Leighton, 1993, figure 5)*

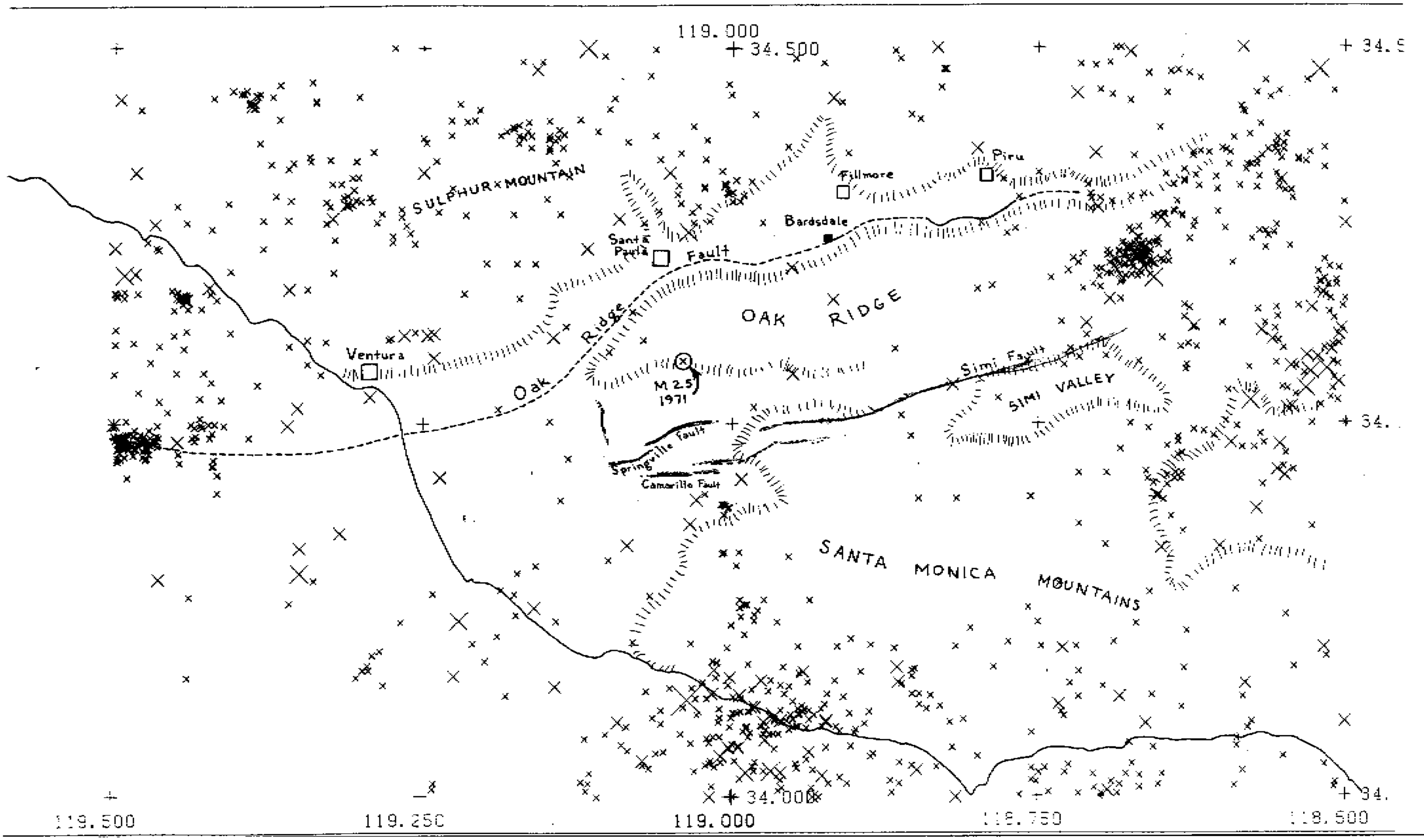
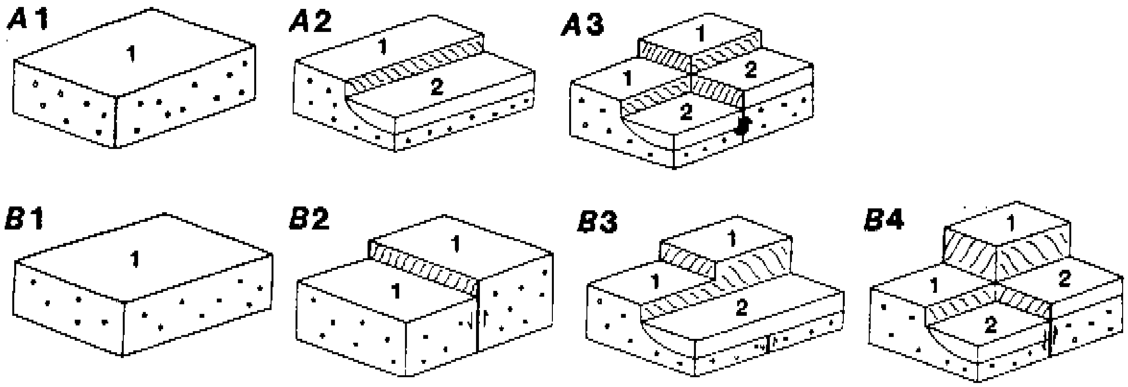


Figure 5 (FER-237) - Seismicity from 1932 to 3/16/89, M1 and greater. *(CalTech earthquake catalogue)*



--Schematic block diagrams of fault scarp/ terrace relations. A. earlier alluvium (1) is deposited, younger terrace (2) is incised into it, then a single faulting event occurs. B. Earlier alluvium is deposited (1), then faulted (2). After faulting a younger terrace is incised into both the upthrown and downthrown blocks (3), then is re-faulted along the same trace (4). The multiple-event scarp on terrace 1 is twice as high as the single-event scarp on terrace 2 if displacements are equal.

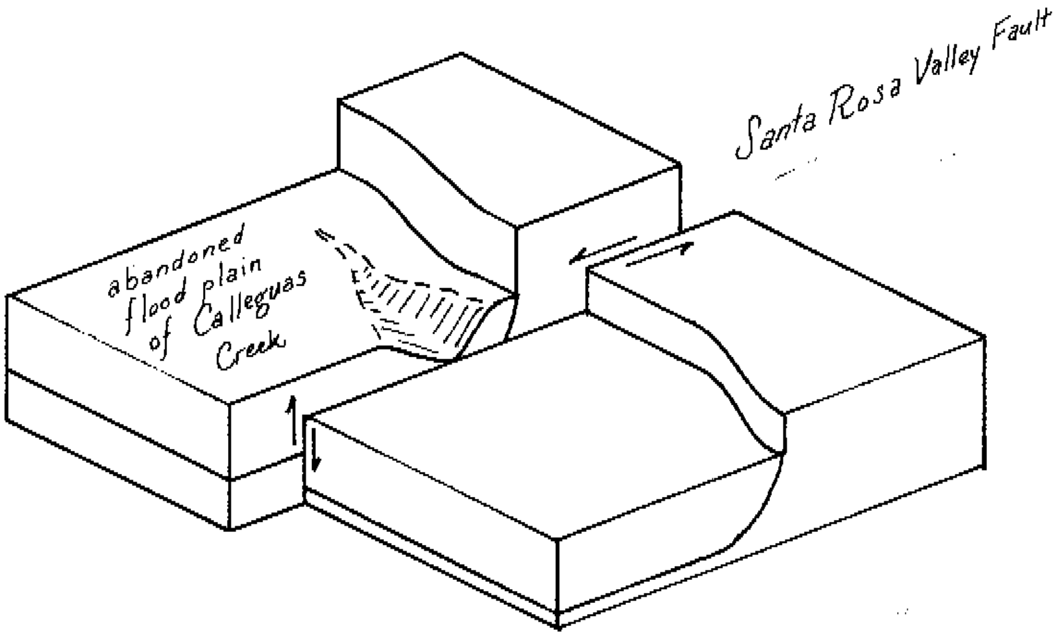


Figure 6 (FER-237) - Upper illustration from McCalpin (1987) showing topographic relationships between faulting and stream terraces. Note that this figure presents a mirror image of the situation at the Calleguas Creek/Santa Rosa Valley Fault intersection. Minor left-lateral displacement is also needed to result in the lower sketch.

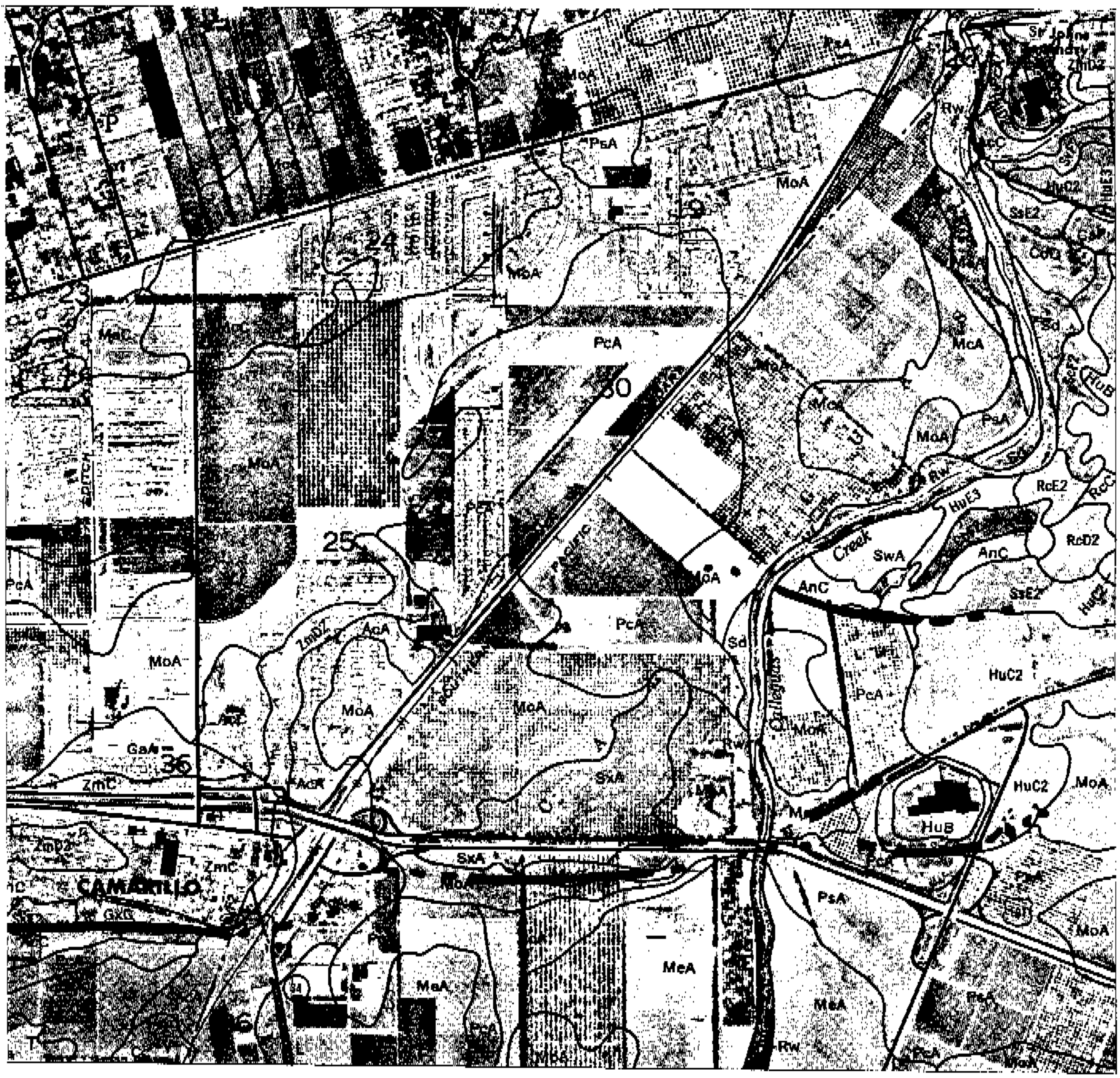


Figure 8 (FER-237) - Portion of Soil Survey (USDA, 1970) map 37 showing soils across the Camarillo and "Santa Rosa Valley" faults.

AnC	Anacapa gravelly sandy loam: A/C profile on 2-9% slopes
Hu...	Huerhuero series: well-developed Bt-horizon; up to 23" thick; 10YR color
McA	Metz loamy fine sand: A/C profile with 7" A-horizon
MeA	Metz loamy sand: A/C profile with 7" A-horizon
MoA	Mocho loam: A/C profile with 16" A-horizon
PcA	Pico sandy loam: A/C profile with 14" A-horizon
SsE2	Soper loam: well-developed 46"-thick B horizon with 7.5YR color; 15-30% slopes
SxA	Sorrento silty clay loam: A/C profile with 19" A-horizon
SwA	Sorrento loam: A/C profile with 19" A-horizon

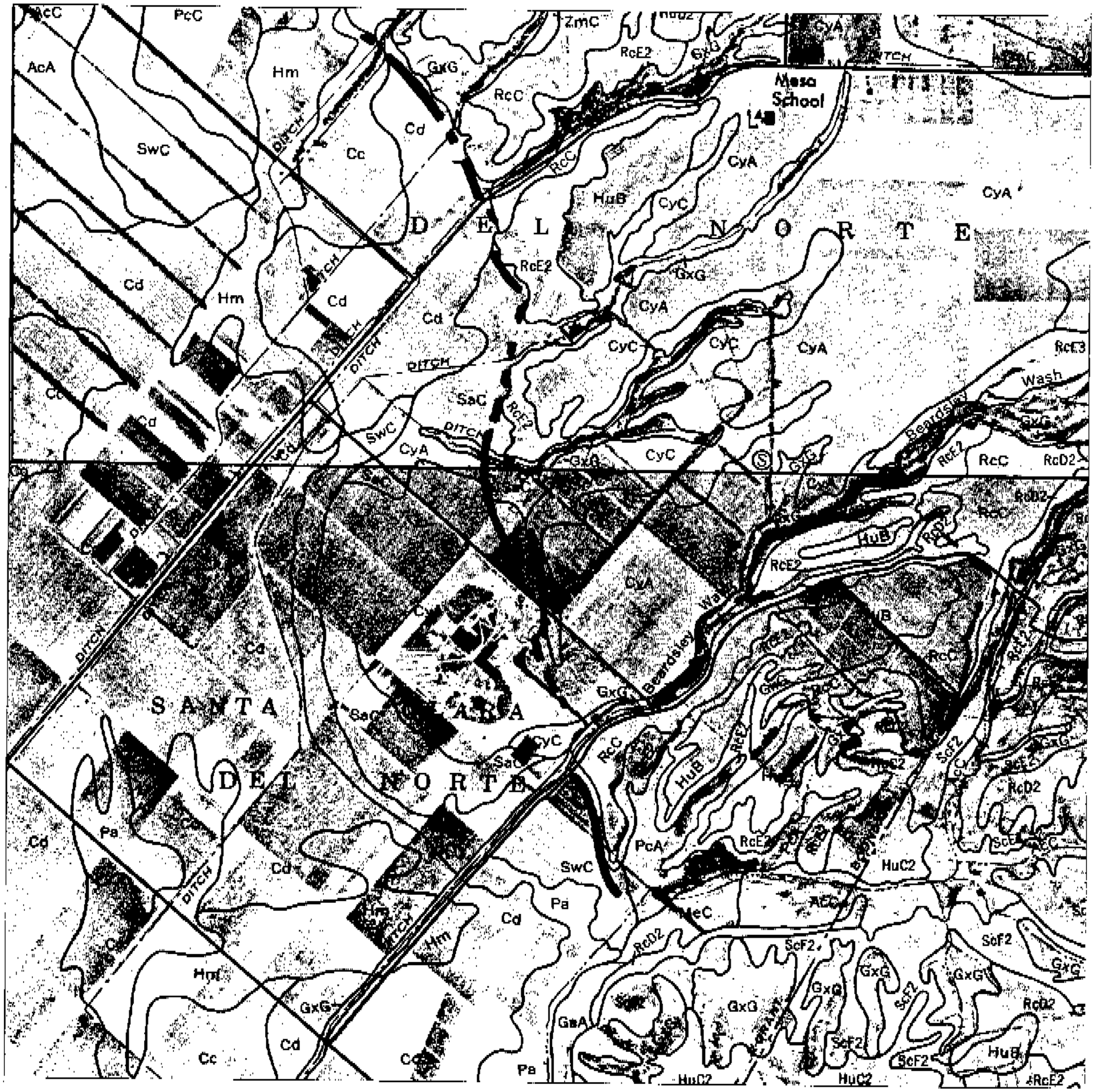
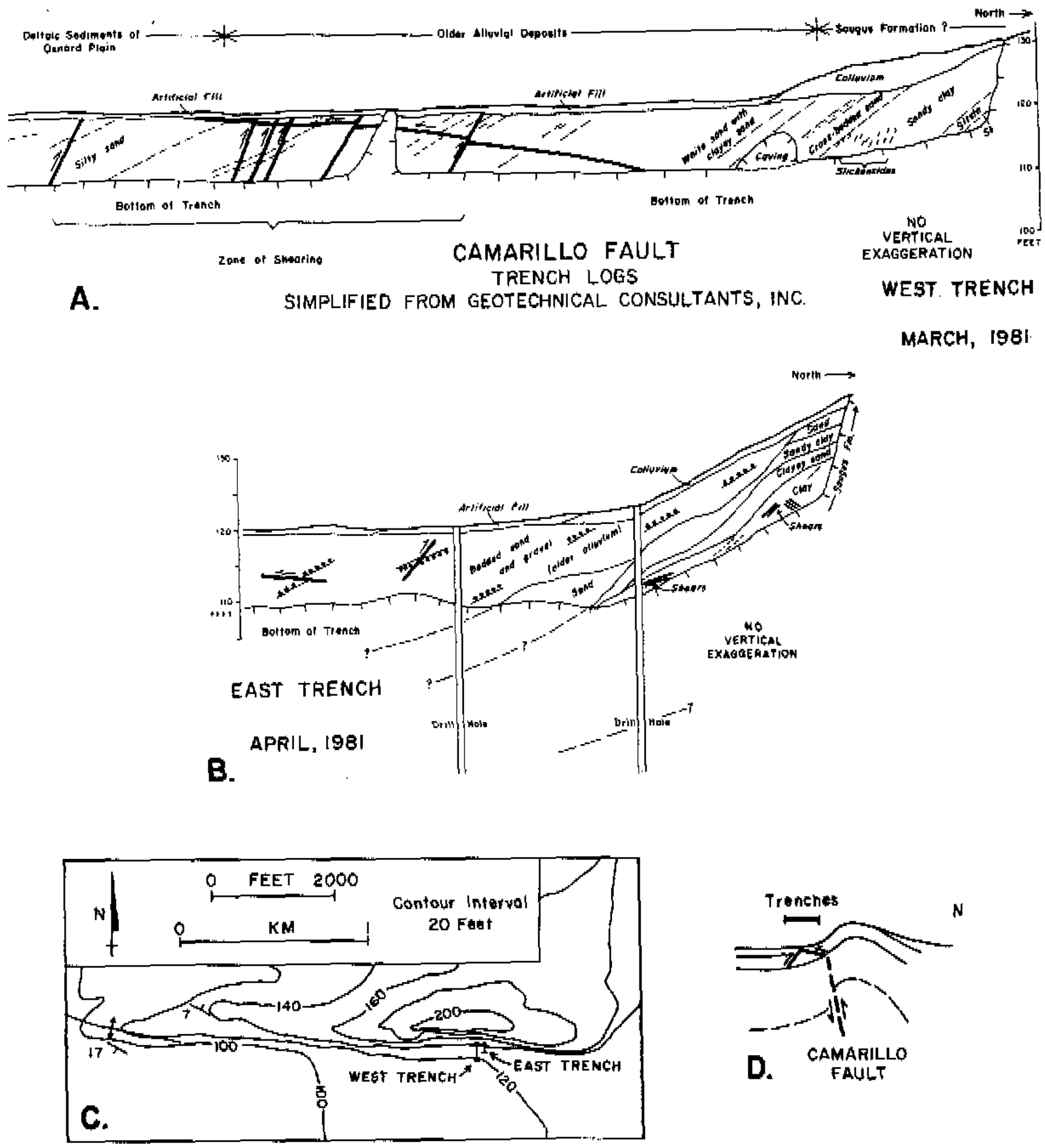


Figure 9 (FER-237) - Portion of Soil Survey (USDA, 1970) maps 24 and 37 showing soils across the "Wright Road Fault".

Cc Camarillo sandy loam: A/C profile with 17"+ A-horizon
Cd Camarillo loam: A/C profile with 17"+ A-horizon
CyA Cropley clay: A/C profile with 22"+ A-horizon
  CyC Cropley clay on 2-9% slopes
HuB Huerhuero v.fine sandy loam: well-developed 23"-thick Bt-horizon, 10YR color
PcA Pico sandy loam: A/C profile with 14" A-horizon
RcC Rincon silty clay loam: well-developed 24"-thick Bt-horizon
  RcE2 Rincon silty clay loam on 15-30% slopes
SaC Salinas clay loam: A/C profile with 26"+ A-horizon; 2-9% slopes
SwC Sorrento loam: A/C profile with 19" A-horizon; 2-9% slopes



(Figure 6a, b.) Simplified sketches of trenches across Camarillo fault, after D. A. Gardner
of Gardner '82) (this volume, and unpublished technical reports by Geotechnical Consultants, Inc.). c. Topography of ridge in downtown Camarillo from U.S. Geol. Survey Camarillo 7½-minute quadrangle, locating two trenches. Camarillo fault is presumed to control steep south flank of this ridge. d. Sketch of presumed relation between bending-moment faults in trenches and subjacent Camarillo fault.

Figure 10 (FER-237) - from Gardner (1982)

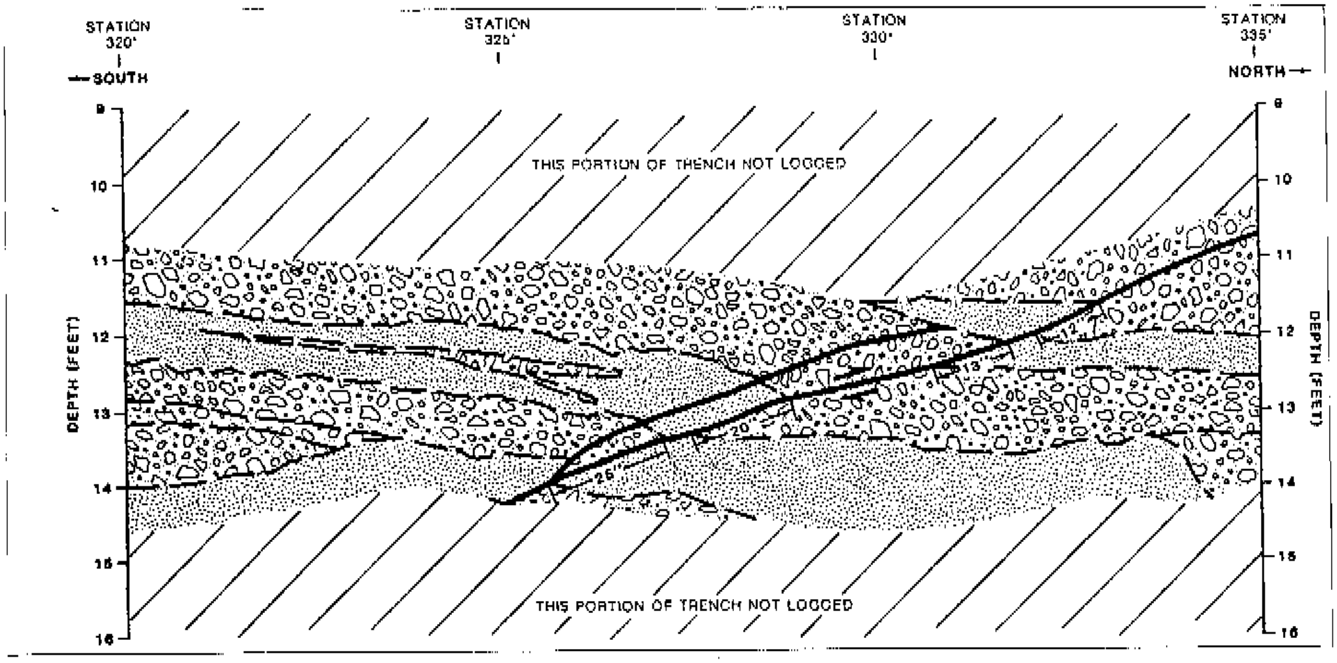


Figure 11 (FER-237) - Sketch log of a trench excavated by Geolabs (1990d). "The faults exposed in the trench are interpreted to be dying-out-upward bending-moment faults. Note that the slip along the lower fault diminishes from 25 inches near base of trench to 12 inches near top, suggesting that perhaps slip may have been accomodated by warping, dilation, and intergranular rotation in the poorly lithified near-surface materials" - quoted from Blake (1991, his fig.8, location G).